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Devendran et al.

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(54) **SYSTEMS AND METHODS FOR DETERMINING PROBLEMATIC PATHS BETWEEN INTEREST POINTS IN A MULTI-CLOUD ENVIRONMENT**

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H04L 43/0852 (2022.01)
(Continued)

(52) **U.S. Cl.**
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CPC . H04L 45/22; H04L 43/0829; H04L 43/0858; H04L 43/087; H04L 43/10;
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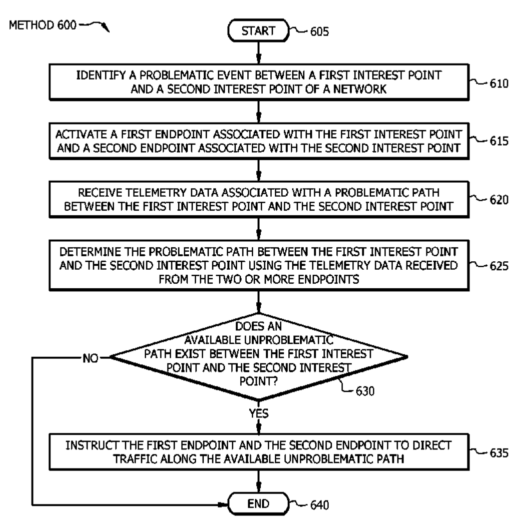
(57) **ABSTRACT**

In one embodiment, a method includes identifying a problematic event between a first interest point and a second interest point of a network and activating, in response to identifying the problematic event between the first interest point and the second interest point, a first endpoint associated with the first interest point and a second endpoint associated with the second interest point. The method also includes receiving, from the first endpoint and the second endpoint, telemetry data associated with a problematic path between the first interest point and the second interest point. The method further includes determining the problematic path between the first interest point and the second interest point using the telemetry data received from the first endpoint and the second endpoint.

20 Claims, 7 Drawing Sheets



(51) **Int. Cl.**

H04L 43/087	(2022.01)
H04L 43/091	(2022.01)
H04L 43/10	(2022.01)
H04L 45/00	(2022.01)
H04L 41/0677	(2022.01)

(58) **Field of Classification Search**
CPC ... H04L 43/0852; H04L 43/091; H04L 43/12; H04L 41/0677
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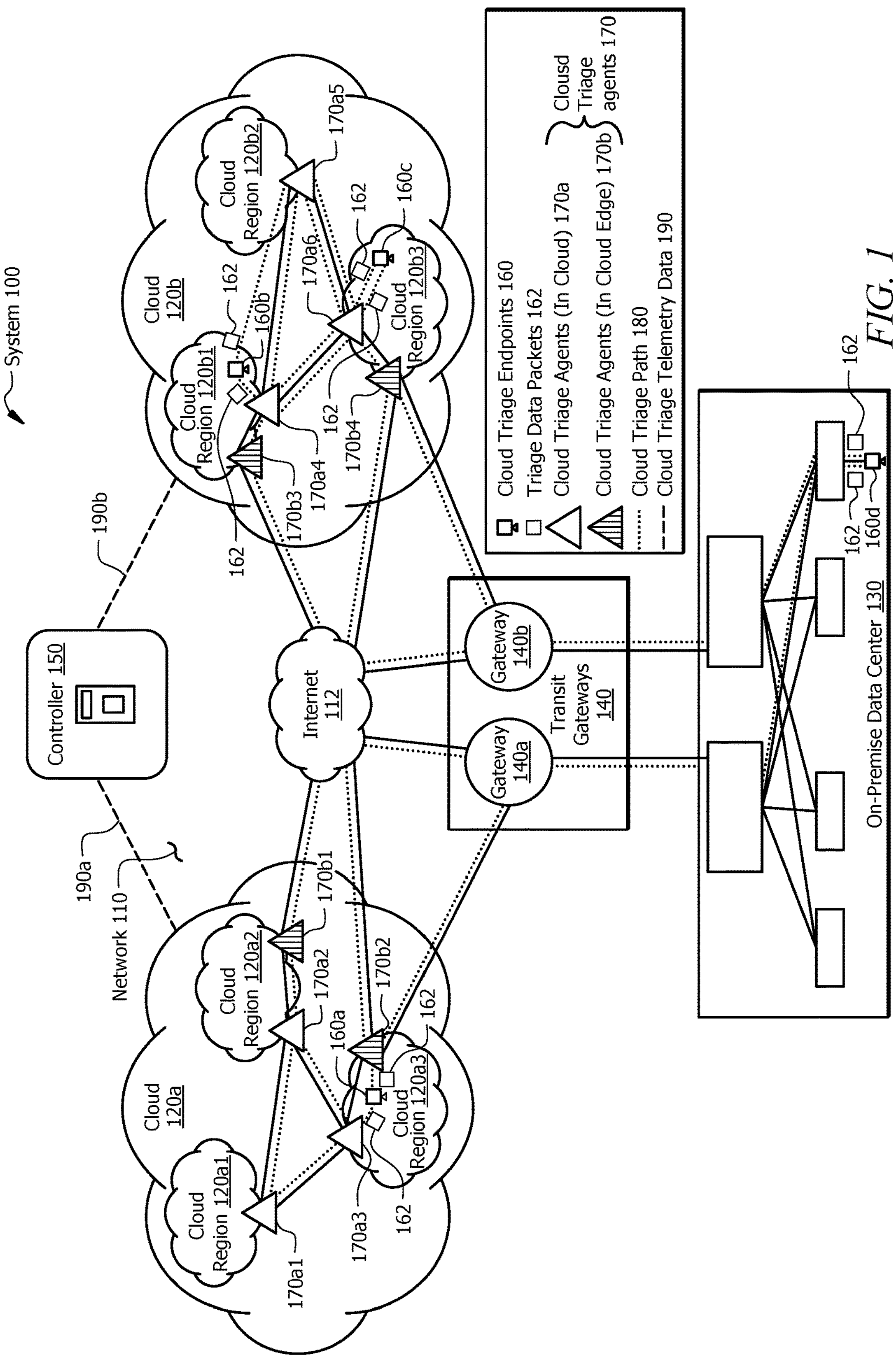
System 100
Controller 150
190a
190b
Network 110
Cloud 120a
Cloud Region 120a1
Cloud Region 120a2
Cloud Region 120a3
Cloud 120b
Cloud Region 120b1
Cloud Region 120b2
Cloud Region 120b3
Internet 112
Gateway 140a
Gateway 140b
Transit Gateways 140
On-Premise Data Center 130
170a1
170a2
170a3
170a4
170a5
170a6
170b1
170b2
170b3
170b4
160a
160b
160c
160d
162
Cloud Triage Endpoints 160
Triage Data Packets 162
Cloud Triage Agents (In Cloud) 170a
Cloud Triage Agents (In Cloud Edge) 170b
Clousd Triage agents 170
Cloud Triage Path 180
Cloud Triage Telemetry Data 190

FIG. 1

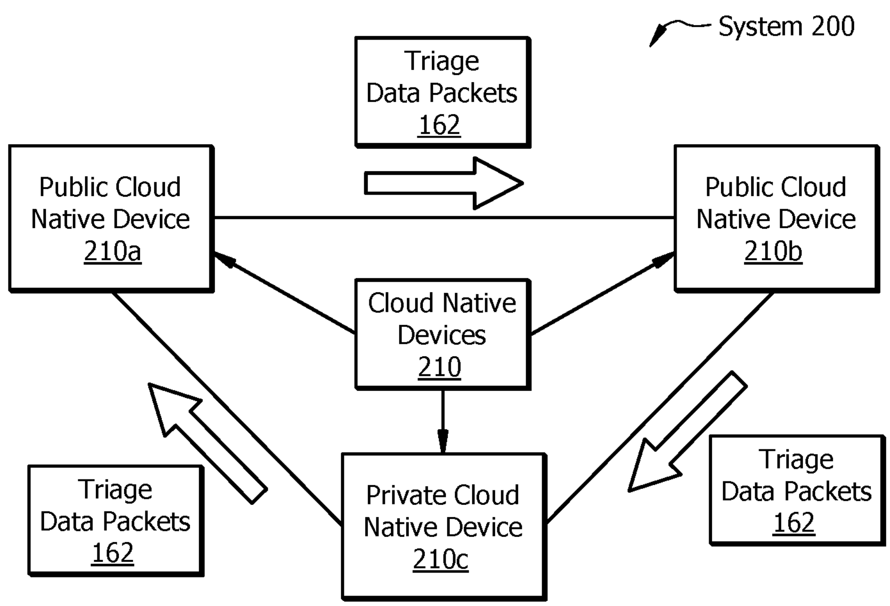
System 200
Triage Data Packets 162
Public Cloud Native Device 210a
Public Cloud Native Device 210b
Cloud Native Devices 210
Triage Data Packets 162
Private Cloud Native Device 210c
Triage Data Packets 162

FIG. 2

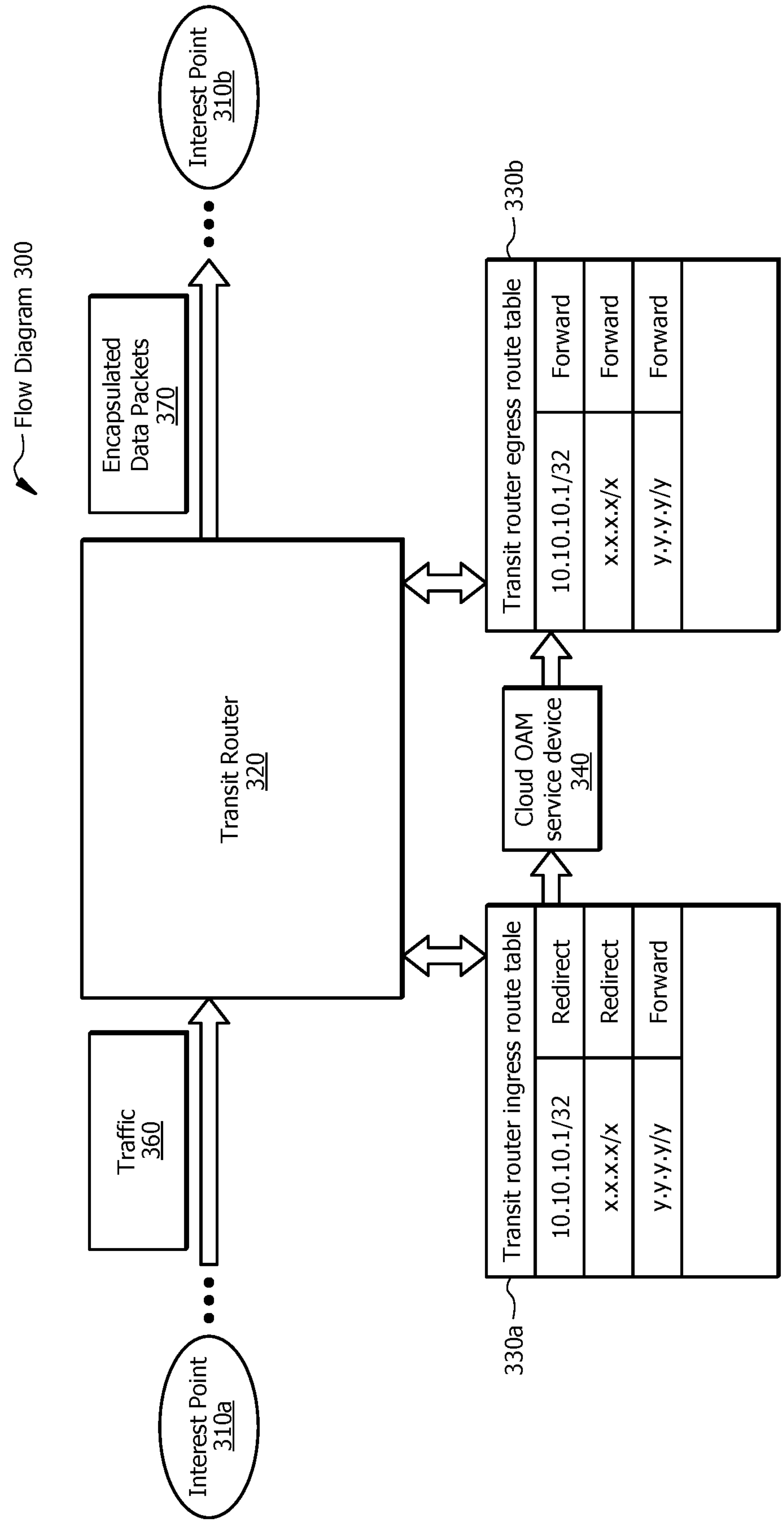
Flow Diagram 300
Interest Point 310a
Traffic 360
Transit Router 320
Encapsulated Data Packets 370
Interest Point 310b
330a
Transit router ingress route table
10.10.10.1/32
Redirect
x.x.x.x/x
Redirect
y.y.y.y/y
Forward
Cloud OAM service device 340
330b
Transit router egress route table
10.10.10.1/32
Forward
x.x.x.x/x
Forward
y.y.y.y/y
Forward

FIG. 3

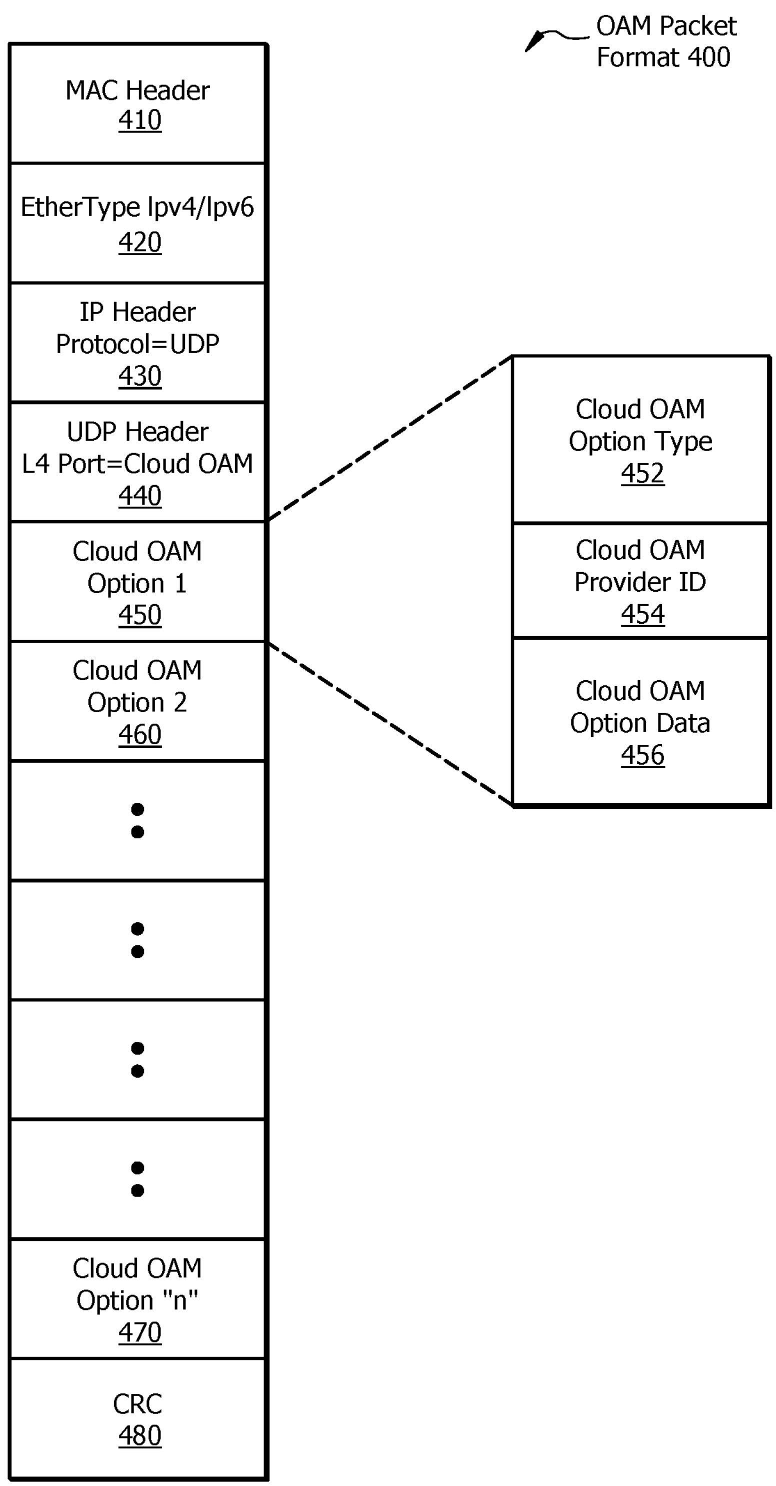
OAM Packet Format 400
MAC Header 410
EtherType Ipv4/Ipv6 420
IP Header Protocol=UDP 430
UDP Header L4 Port=Cloud OAM 440
Cloud OAM Option 1 450
Cloud OAM Option 2 460
Cloud OAM Option "n" 470
CRC 480
Cloud OAM Option Type 452
Cloud OAM Provider ID 454
Cloud OAM Option Data 456

FIG. 4

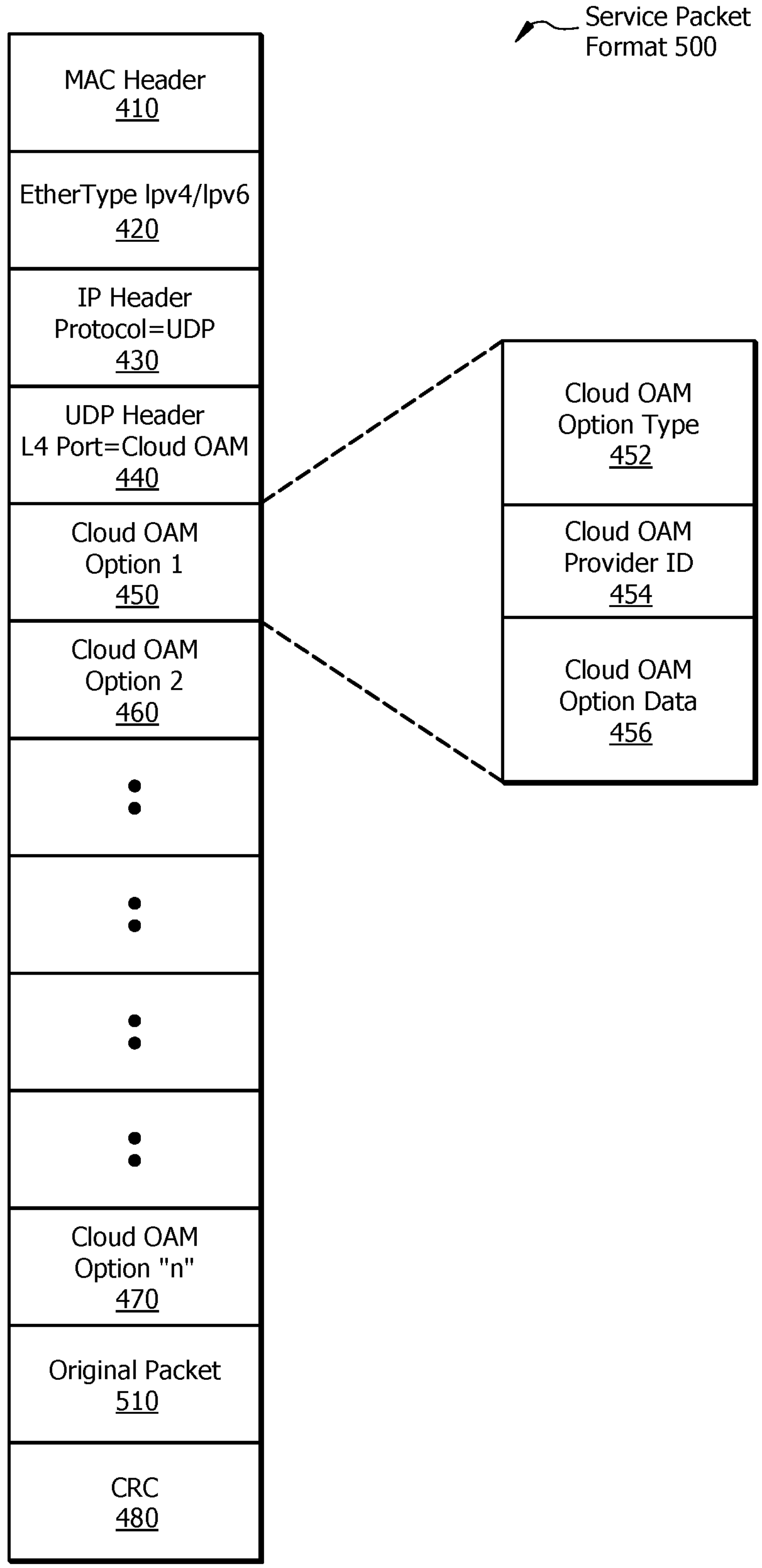
Service Packet
Format 500
MAC Header
410
EtherType Ipv4/Ipv6
420
IP Header
Protocol=UDP
430
UDP Header
L4 Port=Cloud OAM
440
Cloud OAM
Option 1
450
Cloud OAM
Option 2
460
Cloud OAM
Option "n"
470
Original Packet
510
CRC
480
Cloud OAM
Option Type
452
Cloud OAM
Provider ID
454
Cloud OAM
Option Data
456

FIG. 5

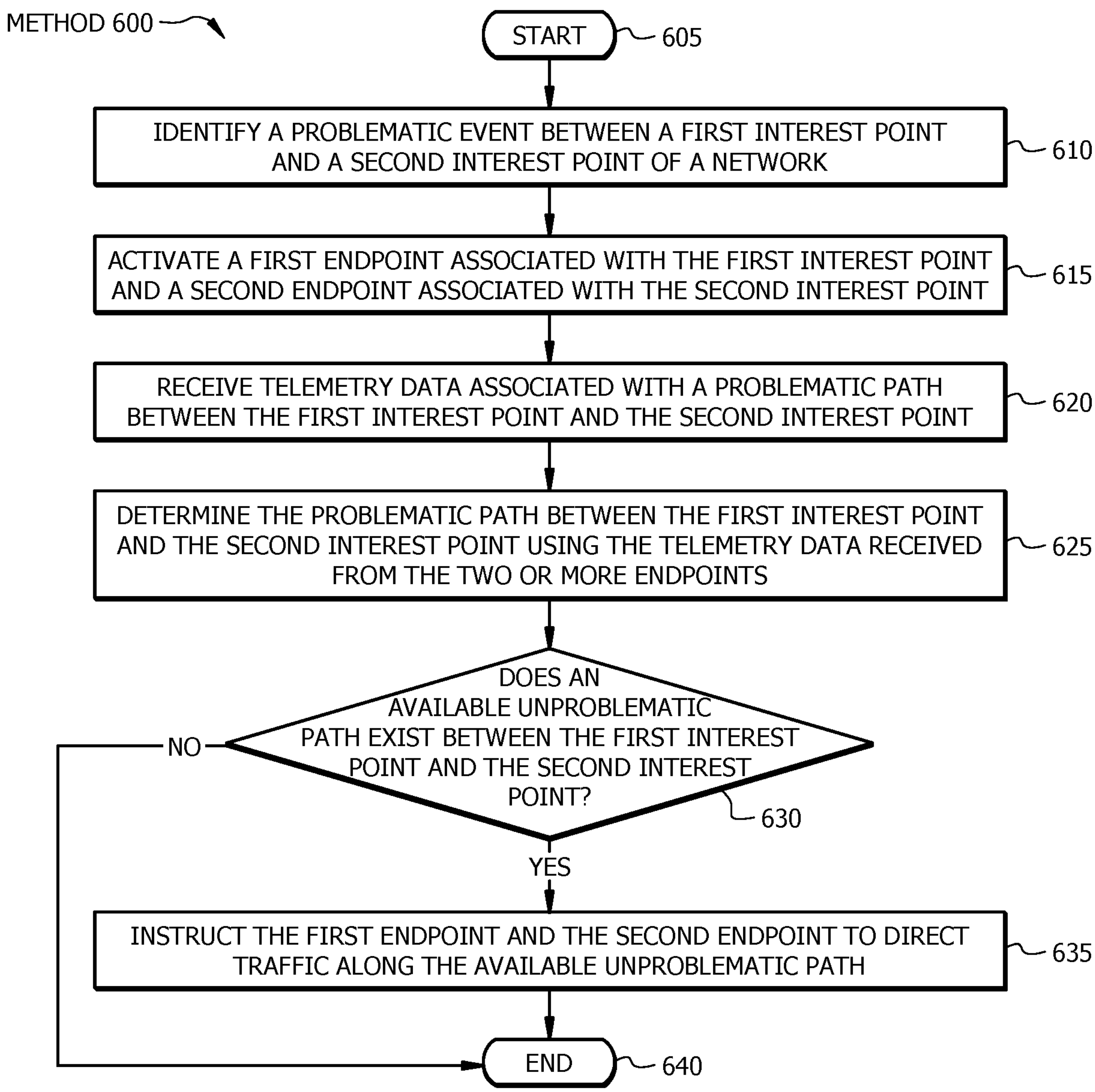
METHOD 600
START
605
IDENTIFY A PROBLEMATIC EVENT BETWEEN A FIRST INTEREST POINT AND A SECOND INTEREST POINT OF A NETWORK
610
ACTIVATE A FIRST ENDPOINT ASSOCIATED WITH THE FIRST INTEREST POINT AND A SECOND ENDPOINT ASSOCIATED WITH THE SECOND INTEREST POINT
615
RECEIVE TELEMETRY DATA ASSOCIATED WITH A PROBLEMATIC PATH BETWEEN THE FIRST INTEREST POINT AND THE SECOND INTEREST POINT
620
DETERMINE THE PROBLEMATIC PATH BETWEEN THE FIRST INTEREST POINT AND THE SECOND INTEREST POINT USING THE TELEMETRY DATA RECEIVED FROM THE TWO OR MORE ENDPOINTS
625
DOES AN AVAILABLE UNPROBLEMATIC PATH EXIST BETWEEN THE FIRST INTEREST POINT AND THE SECOND INTEREST POINT?
630
NO
YES
INSTRUCT THE FIRST ENDPOINT AND THE SECOND ENDPOINT TO DIRECT TRAFFIC ALONG THE AVAILABLE UNPROBLEMATIC PATH
635
END
640

FIG. 6

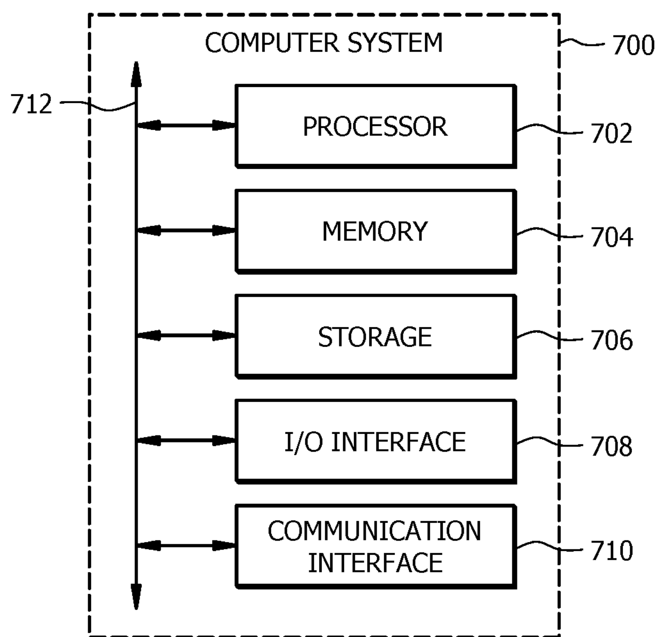
COMPUTER SYSTEM
700
712
PROCESSOR
702
MEMORY
704
STORAGE
706
I/O INTERFACE
708
COMMUNICATION INTERFACE
710

FIG. 7

SYSTEMS AND METHODS FOR DETERMINING PROBLEMATIC PATHS BETWEEN INTEREST POINTS IN A MULTI-CLOUD ENVIRONMENT

PRIORITY

This nonprovisional application is a continuation, under 35 U.S.C. § 120, of U.S. patent application Ser. No. 17/390,511 filed on Jul. 30, 2021, and entitled "SYSTEMS AND METHODS FOR DETERMINING PROBLEMATIC PATHS BETWEEN INTEREST POINTS IN A MULTI-CLOUD ENVIRONMENT," all of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates generally to communication networks, and more specifically to systems and methods for determining problematic paths between interest points in a multi-cloud environment.

BACKGROUND

Public clouds are computing services offered by third-party providers over the Internet. Public clouds provide platforms for deploying applications easily and instantly, which may reduce or eliminate the need to maintain on-premise infrastructure and Information Technology (IT) staff. Traffic in public clouds has increased exponentially as applications are built and hosted in public clouds directly. In certain instances, on-premise infrastructure is decommissioned as on-premise applications are migrated to public clouds.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an example system for determining problematic paths between interest points in a multi-cloud environment;

FIG. **2** illustrates another example system for determining problematic paths between interest points in a multi-cloud environment;

FIG. **3** illustrates an example flow diagram for determining problematic paths between interest points in a multi-cloud environment;

FIG. **4** illustrates an example OAM packet format;

FIG. **5** illustrates an example service packet format;

FIG. **6** illustrates an example method for determining problematic paths between interest points in a multi-cloud environment; and

FIG. **7** illustrates an example computer system that may be used by the systems and methods described herein.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

According to an embodiment, a controller includes one or more processors and one or more computer-readable non-transitory storage media coupled to the one or more processors and including instructions that, when executed by the one or more processors, cause the controller to perform operations. The operations include identifying a problematic event between a first interest point and a second interest point of a network and activating, in response to identifying the problematic event between the first interest point and the second interest point, a first endpoint associated with the first interest point and a second endpoint associated with the second interest point. The operations also include receiving, from the first endpoint and the second endpoint, telemetry data associated with a problematic path between the first interest point and the second interest point. The operations further include determining the problematic path between the first interest point and the second interest point using the telemetry data received from the first endpoint and the second endpoint.

In certain embodiments, the operations include activating one or more cloud agents within the network. The operations may include receiving, from the one or more cloud agents, additional telemetry data associated with the path between the first interest point and the second interest point. The operations may include computing the path between the first interest point and the second interest point using the additional telemetry data received from the one or more cloud agents. In some embodiments, the operations include instructing one or more transit routers within the network to redirect an identified traffic flow to a cloud agent.

In certain embodiments, activating the first endpoint and the second endpoint initiates a generation of Operations, Administration, and Maintenance (OAM) data packets by the first endpoint and the second endpoint. The telemetry may be collected by the OAM data packets. In certain embodiments, the telemetry data includes one or more of the following: an identification of a cloud region; an identification of availability zones; a location of a cloud edge; an identification of a path type; latency; and jitter.

In some embodiments, each of the first interest point and the second interest point are associated with one of the following: a public cloud; a private cloud; or an on-premise data center. In certain embodiments, the problematic event is associated with at least one of the following network characteristics: latency; jitter; or packet drop.

According to another embodiment, a method includes identifying a problematic event between a first interest point and a second interest point of a network and activating, in response to identifying the problematic event between the first interest point and the second interest point, a first endpoint associated with the first interest point and a second endpoint associated with the second interest point. The method also includes receiving, from the first endpoint and the second endpoint, telemetry data associated with a problematic path between the first interest point and the second interest point. The method further includes determining the problematic path between the first interest point and the second interest point using the telemetry data received from the first endpoint and the second endpoint.

According to yet another embodiment, one or more computer-readable non-transitory storage media embody instructions that, when executed by a processor, cause the processor to perform operations. The operations include identifying a problematic event between a first interest point and a second interest point of a network and activating, in response to identifying the problematic event between the first interest point and the second interest point, a first endpoint associated with the first interest point and a second endpoint associated with the second interest point. The operations also include receiving, from the first endpoint and the second endpoint, telemetry data associated with a problematic path between the first interest point and the second interest point. The operations further include determining the problematic path between the first interest point and the second interest point using the telemetry data received from the first endpoint and the second endpoint.

Technical advantages of certain embodiments of this disclosure may include one or more of the following. This disclosure provides a cloud agnostic solution that can be used within regions of a single cloud environment, a multi-cloud environment, and/or hybrid-cloud environment for cloud native visibility and fault detection/correction. In certain embodiments, cloud triage is triggered automatically between two workload interest points when there is an anomaly detected. The disclosure includes methods for detecting configuration mis-programming errors and reporting the location and error code. In certain embodiments of the disclosure, the disclosed systems and methods measure latency segments between end-to-end paths. In some embodiments, the disclosed methods and systems detect and/or report packet drops in every segment along an end-to-end path. Since the entire cloud triage schema may be integrated with an Software-defined wide area network (SD-WAN) controller in certain embodiments, the controller can use this information to zoom into where the fault occurred and report the root cause of fault in a single pane of glass. The operations of the cloud administrators are thus simplified since the SD-WAN controller can recommend corrective steps to repair the fault and/or autocorrect. In the area of multi-cloud networking, this disclosure may provide a competitive advantage in normalizing triaging across various cloud vendors.

Other technical advantages will be readily apparent to one skilled in the art from the following figures, descriptions, and claims. Moreover, while specific advantages have been enumerated above, various embodiments may include all, some, or none of the enumerated advantages.

EXAMPLE EMBODIMENTS

This disclosure describes systems and methods for determining problematic paths between interest points in a multi-cloud environment. SD-WAN solutions are currently capable of directing traffic based on service-level agreement (SLA) definitions. Application traffic patterns and graphs may be associated with one or more clouds. Application traffic may include cloud traffic (e.g., Amazon Web Services (AWS) traffic), multi-cloud traffic (e.g. AWS and Microsoft Azure ("Azure") traffic), hybrid cloud traffic (e.g., AWS and on-premise traffic, Microsoft Azure and public traffic, etc.), or a combination thereof. Debugging and trouble-shooting breakages or problems in these traffic patterns may prove challenging, particularly in multi-cloud and hybrid-cloud cases since each public cloud's instrumentation is proprietary and may not provide cross-domain fault detection, visibility, telemetry, and/or isolation of faults for root cause analysis and fault recovery. In certain embodiments, application traffic packet flow can traverse: a cloud platform native network (e.g., an AWS backbone connecting multiple regions), a public Internet for multi-cloud or cloud to-on-premise hybrid cloud flows, cloud provider leased line networks for cloud-to-on-premise (e.g., Direct connect in AWS, ExpressRoute in Azure, etc.), cloud-to-cloud connectivity through a co-location provider (e.g., Megaport), and the like.

Because application traffic flow from point A to point B may have "n" number of paths and the packets may take any one of the paths based on the forwarding decision taken by the packet switch/route components in the cloud, visibility and fault isolation becomes difficult. Due to these complex heterogeneous networks, no known solution exists today to triage these public cloud networking problems. For example, current solutions cannot exactly identify a fault causing increased latency in the packet flows and/or workloads to perform poorly. In the public cloud, the maximum visibility available today is that a given cloud region/availability zone is performing below optimum. This disclosure provides systems and methods for determining the cause of the issue or, if needed, to find alternate paths to switch the traffic to a "best" path to increase the workload performance and improve customer experience.

FIG. **1** illustrates an example system **100** for determining problematic paths between interest points in a multi-cloud environment. System **100** or portions thereof may be associated with an entity, which may include any entity, such as a business, company, or enterprise, that determining problematic paths between interest points in a multi-cloud environment. In certain embodiments, the entity may be a service provider that provides networking services (e.g., Internet, Ethernet, optical, wireless, mobility, cloud computing, etc.). The components of system **100** may include any suitable combination of hardware, firmware, and software. For example, the components of system **100** may use one or more elements of the computer system of FIG. **7**. In the illustrated embodiment of FIG. **1**, system **100** includes a network **110**, clouds **120**, an on-premise data center **130**, transit gateways **140**, a controller **150**, cloud triage endpoints **160**, tirage data packets **162**, and cloud triage agents **170**.

Network **110** of system **100** is any type of network that facilitates communication between components of system **100**. Network **110** may connect one or more components of system **100**. One or more portions of network **110** may include an ad-hoc network, an intranet, an extranet, a virtual private network (VPN), an Ethernet VPN (EVPN), a local area network (LAN), a wireless LAN (WLAN), a virtual LAN (VLAN), a wide area network (WAN), a wireless WAN (WWAN), an SD-WAN, a metropolitan area network (MAN), a portion of Internet **112**, a portion of the Public Switched Telephone Network (PSTN), a cellular telephone network, a Digital Subscriber Line (DSL), an Multiprotocol Label Switching (MPLS) network, a 3G/4G/5G network, a Long Term Evolution (LTE) network, a cloud network, a combination of two or more of these, or other suitable types of networks. Network **110** may include one or more different types of networks. Network **110** may be any communications network, such as a private network, a public network, a connection through Internet **112**, a mobile network, a WI-FI network, etc. One or more components of system **100** may communicate over network **110**. Network **110** may include a core network (e.g., Internet **112**), an access network of a service provider, an Internet service provider (ISP) network, and the like.

Network **110** may include one or more nodes. Nodes are connection points within network **110** that receive, create, store and/or send data along a path. Nodes may include one or more redistribution points that recognize, process, and forward data to other nodes of network **110**. Nodes may include virtual and/or physical nodes. For example, nodes may include one or more virtual machines, bare metal servers, and the like. As another example, nodes may include data communications equipment such as routers (e.g., edge routers, headend routers, etc.), servers, printers, workstations, switches, bridges, modems, hubs, and the like. In the illustrated embodiment of FIG. **1**, network **110** includes clouds **120**, on-premise data center **130**, transit gateways **140**, and controller **150**.

Clouds **120** of system **100** are platforms that offer services via one or more remote cloud computing network elements (e.g., routers, servers, gateways, etc.). Cloud computing is an on-demand availability of computer system resources, such as data storage and computing power, without direct active management by the user. Clouds **120** may be associated with one or more of the following cloud service providers: AWS, Microsoft Azure, Google Cloud, Alibaba Cloud, IBM Cloud, Oracle, Salesforce, SAP, Rackspace Cloud, VMWare, etc. For example, cloud **120***a* may be a Microsoft Azure cloud computing service, and cloud **120***b* may be an AWS cloud computing service. In certain embodiments, clouds **120** are offered in different service models based on business requirements. Cloud service models may include Software as a Service (Saas), Platform as a Service (PaaS), Infrastructure as a Service (IaaS), Function as a Service (FaaS), Internet **112**, one or more private cloud services, and the like.

In the illustrated embodiment of FIG. **1**, clouds **120** include cloud regions. Each cloud region is a geographic location where the cloud resources (e.g., data centers) are located. In certain embodiments, each cloud region may include a set of data centers deployed within a latency-defined perimeter and connected through a dedicated regional low-latency network. In the illustrated embodiment of FIG. **1**, cloud **120***a* includes cloud region **120***al*, cloud region **120***a***2**, and cloud region **120***a***3**, and cloud **120***b* includes cloud region **120***b***1**, cloud region **120***b***2**, and cloud region **120***b***3**. Cloud regions may span multiple cities, states, and/or countries. For example, cloud region **120***al* may be located in US East (Ohio), cloud region **120***a***2** may be located in US East (Virginia), and cloud region **120***a***3** may be located in US West (Oregon). As another example, cloud region **120***b***1** may be located in Asia Pacific (Hong Kong), cloud region **120***b***2** may be located in Europe (Paris), and cloud region **120***b***3** may be located in China (Beijing).

On-premise data center **130** of system **100** is a collection of network components that are privately owned and controlled. In certain embodiments, an enterprise may run software and store data in its own on-premise data center **130**. In some embodiments, one or more users may lease data center resources stored in on-premise data center **130** from a third-party service provider. Transit gateways **140** of system **100** are transit hubs used to interconnect cloud and on-premises networks. In the illustrated embodiment of FIG. **1**, transit gateways **140** of system **100** connect cloud **120***a*, cloud **120***b*, and on-premise data center **130** through a central hub.

Controller **150** of system **100** is a component that manages and directs the flow of traffic within network **110**. In certain embodiments, controller **150** is an SD-WAN controller. Controller **150** may include one or more smart controllers, management controllers, orchestrators, and the like. Controller **150** may be deployed by any entity such as a business, a company, an enterprise, and the like. In certain embodiments, controller **150** is associated with an entity such as a service provider (e.g., an ISP or a cloud service provider). In some embodiments, controller **150** receives data (e.g., telemetry data) from one or more components of system **100**. Controller **150** may record the received telemetry data and/or store the telemetry data in a database. Controller **150** may include one or more components of the computer system of FIG. **7**.

Cloud triage endpoints **160** of system **100** are nodes within network **110** that may be activated on demand by controller **150**. Cloud triage endpoints **160** may be activated in response to a problematic event within network **110**. For example, controller **150** may identify one or more interest points (i.e., instances that host workloads impacted by a problematic event) within network **110** and activate, in response to identifying the interest points, cloud triage endpoints **160** associated with the identified interest points. In the illustrated embodiment of FIG. **1**, cloud triage endpoints include cloud triage endpoint **160***a* located in cloud region **120***a***3** of cloud **120***a*, cloud triage endpoint **160***b* located in cloud region **120***b***1** of cloud **120***b*, cloud triage endpoint **160***c* located in cloud region **120***b***3** of cloud **120***b*, and cloud triage endpoint **160***d* located in on-premise data center **130**.

In certain embodiments, the path between two interest points may be the underlying cloud provider native networks or the virtual appliance-based network built on top of the cloud native networks. The activation of cloud triage endpoints **160** may be triggered by a network problematic event that occurred between the interest points and requires corrective action. The problematic event may be an introduction of latency, jitter, or packet drop in a current active path between the interest points that is causing the services and/or workloads on the interest points to work at sub-optimal level. In certain embodiments, once activated, cloud triage endpoints **160** trigger the generation of triage data packets **162** within network **110**. Triage data packets **162** are packets used to monitor and collect data about network **110**. For example, triage data packets **162** may collect cloud triage telemetry data **190** from one or more nodes along cloud triage paths **180**. In the illustrated embodiment of FIG. **1**, triage data packets **162** carry OAM information. OAM are the processes, activities, tools, and/or standards involved with operating, administering, maintaining, and/or managing system **100**. OAM telemetry data may include information such as such as node ID, ingress interface ID, egress interface ID, timestamp, Proof of Transit, sequence numbers, application metadata, generic customer data, and the like. The bidirectional nature of the triage signal may prove useful to triage if asymmetry in cloud triage paths **180** exist between the interest points. Cloud triage endpoints **160** stream cloud triage telemetry data **190** (see notations **190***a* and **190***b* of FIG. **1**) collected by triage data packets **162** back to controller **150**.

Triage data packets **162** generated by the cloud triage endpoints **160** may include Type-Length-Values (TLV) options to capture cloud triage telemetry data **190**. Triage information may include granular details such as the identifications of cloud regions, the identifications of availability zones, the locations of cloud edges, the types of paths traversed by triage data packets **162**, latency, jitter (e.g., jitter introduced by the packet exchanges or the traversed path), and the like. Controller **150** may use the triage information to determine the problematic path between the two interest points. In certain embodiments, controller **150** uses the triage information to determine the primary path between two interest points, available secondary paths, and "best" paths.

Cloud triage agents **170** are applications that collect data from one or more network components of network **110**. Cloud triage agents **170** may be integrated as IaaS on one or more clouds **120**. In the illustrated embodiment of FIG. **1**, cloud triage agent **170***al* is located in cloud region **120***al* of cloud **120***a*, cloud triage agent **170***a***2** is located in cloud region **120***a***2** of cloud **120***a*, cloud triage agent **170***a***3** is located in cloud region **120***a***3** of cloud **120***a*, cloud triage agent **170***a***4** is located in cloud region **120***b***1** of cloud **120***b*, cloud triage agent **170***a***5** is located in cloud region **120***b***2** of cloud **120***b*, and cloud triage agent **170***a***6** is located in cloud region **120***b***3** of cloud **120***b*.

Cloud triage agents **170** may include one or more edge cloud triage agents **170***b* located at a cloud edge. Edge cloud triage agents **170***b* may be used to determine the entry and exit points of the respective cloud network from/to public Internet **112** or other leased line paths like AWS DX or Azure ER. The identifications of the entry and exits points of each cloud **120** may provide controller **150** with more in-depth information of cloud triage paths **180**, which may assist controller **150** in making decision to recover from faulty network paths. In the illustrated embodiment of FIG. **1**, edge cloud triage agent **170***b***1** is located at the edge of cloud region **120***a***2** of cloud **120***a*, edge cloud triage agent **170***b***2** is located at the edge of cloud region **120***a***3** of cloud **120***a*, edge cloud triage agent **170***b***3** is located at the edge cloud region **120***b***1** of cloud **120***b*, and edge cloud triage agent **170***b***4** is located at the edge of cloud region **120***b***3** of cloud **120***b*.

In certain embodiments, cloud triage agents **170** are inserted onto cloud packet exchanges that switch and route the cloud workload traffic. A cloud packet exchange may be a native packet router or a virtual appliance-based packet switching/routing node. In some embodiments, cloud triage agents **170** intercept cloud triage packets **162** and perform packet modification to insert the required custom triage data to a level of identifying the actual forwarding problem that is impacting the workloads on the interest points. Triage agent packet replication may be used to discover all the available paths for an end-to-end path triage between the interest points, which may provide a complete representation of the network paths between the interest points.

In certain embodiments, cloud triage agents **170** stream triage telemetry data **190** (see notations **190***a* and **190***b*) back to controller **150**. Controller **150** may use cloud triage telemetry data **190** received from one or more cloud triage agents **170** to determine one or more actions to resolve the network problem and/or improve the user experience. In some embodiments, cloud triage agents **170** stream cloud triage telemetry data **190** for the signal packet drop with such granular details to allow controller **150** to isolate the cause of excessive latency, jitter, packet drop, etc. In addition to packet drop telemetry, cloud triage agents **170** may stream cloud triage telemetry data **190** of a particular triage signal to controller **150** to build the path even before the triage signal reaches the interest points where cloud triage endpoints **160** are running. With this approach, error correction in triaging may be achieved in controller **150** by co-relating cloud triage telemetry data **190** received from cloud triage agents **170** and cloud triage telemetry data **190** received from cloud triage endpoints **160**.

In operation, controller **150** identifies a problematic event between a first interest point and a second interest point of network **110**. The first interest point may be associated with a first public cloud (e.g., Azure) and the second interest point may be associated with a second public cloud (e.g., AWS). Controller **150** activates, in response to identifying the problematic event between the first interest point and the second interest point, cloud triage endpoints **160** and/or cloud triage agents **170** associated with the first interest point and a second endpoint associated with the second interest point. Cloud triage endpoints **160** initiate triage data packets **162** along the available paths from the first interest point to the second interest point. Triage data packets **162** collect cloud triage telemetry data **190** that may include cloud region identifications, availability zone indications, cloud edge locations, path type identifications, latency, jitter, packet drop, etc. Controller **150** receives (see notations **190***a* and **190***b*), from activated cloud triage endpoints **160** and/or cloud triage agents **170**, cloud triage telemetry data **190** associated with a problematic path between the first interest point and the second interest point. Controller **150** determines the problematic path between the first interest point and the second interest point using the telemetry data received from activated cloud triage endpoints **160**. and/or cloud triage agents **170**. As such, controller **150** may provide visibility and problem information to a user by analyzing cloud triage telemetry data **190** received from cloud triage endpoints **160** and/or cloud triage agents **170**. The computation result may be viewed by administrators to take corrective actions, or the results may be fed to autocorrection components operable to reprogram/reroute workload data flows to achieve optimum performance and better user experience.

Although FIG. **1** illustrates a particular number of networks **110**, clouds **120**, on-premise data centers **130**, transit gateways **140**, controllers **150**, cloud triage endpoints **160**, triage data packets **162**, and cloud triage agents **170**, this disclosure contemplates any suitable number of networks **110**, clouds **120**, on-premise data centers **130**, transit gateways **140**, controllers **150**, cloud triage endpoints **160**, triage data packets **162**, and cloud triage agents **170**. For example, system **100** may include more or less than two clouds **120**, more than one on-premise data center **130**, more or less than two transit gateways **140**, and/or more than one controller **150**.

Although FIG. **1** illustrates a particular arrangement of network **110**, clouds **120**, on-premise data center **130**, transit gateways **140**, controller **150**, cloud triage endpoints **160**, triage data packets **162**, and cloud triage agents **170**, this disclosure contemplates any suitable arrangement of network **110**, clouds **120**, on-premise data center **130**, transit gateways **140**, controller **150**, cloud triage endpoints **160**, triage data packets **162**, and cloud triage agents **170**. Furthermore, although FIG. **1** describes and illustrates particular components, devices, or systems carrying out particular actions, this disclosure contemplates any suitable combination of any suitable components, devices, or systems carrying out any suitable actions. For example, one or more cloud triage endpoints **160** of system **100** may perform one or more troubleshooting actions of system **200**.

FIG. **2** illustrates another example system **200** for determining problematic paths between interest points in a multi-cloud environment. FIG. **2** includes triage data packets **162** (as described above in FIG. **1**) and cloud devices **210**. Cloud devices **210** include public cloud native device **210***a*, public cloud native device **210***b*, and private cloud native device **210***c*. Public cloud native device **210***a* and public cloud native device **210***b* are associated with public clouds. In certain embodiments, public clouds provide services that share computing services among different customers, even though each customer's data and applications running in the cloud may remain hidden from other cloud customers. Private cloud native device **210***c* is associated with a private cloud. In certain embodiments, private clouds provide services that are not shared with any other organization.

In the illustrated embodiment of FIG. **2**, a controller (e.g., controller **150** of FIG. **1**) enables the OAM functionality on public cloud native device **210***a*, public cloud native device **210***b*, and private cloud native device **210***c* using the respective application programming interface (API) associated with each cloud native device. Triage data packets **162** are generated from each cloud native device **210** and replicated by receiving cloud native device **210**. In the illustrated embodiment of FIG. **2**, triage data packets **162** are "out-of-band" OAM packets. "Out-of-band" indicates that the packets are specifically dedicated to OAM and therefore are transferred independent from the original data packets. In certain embodiments, triage data packets **162** of FIG. **2** use OAM packet format **400** described below in FIG. **4**. Triage data packets **162** collect and carry telemetry data (e.g., cloud triage telemetry data **190** of FIG. **1**) such as cloud region identifications, availability zone indications, cloud edge locations, path type identifications, latency, jitter, packet drop, etc.

Although FIG. **2** illustrates a particular number of cloud devices **210** and triage data packets **162**, this disclosure contemplates any suitable number of cloud devices **210** and triage data packets **162**. For example, system **200** may include one or more on-premise data center devices. Although FIG. **2** illustrates a particular arrangement of cloud devices **210** and triage data packets **162**, this disclosure contemplates any suitable arrangement of cloud devices **210** and cloud triage data packets **162**. For example, triage data packets **162** may flow bidirectionally. Furthermore, although FIG. **2** describes and illustrates particular components, devices, or systems carrying out particular actions, this disclosure contemplates any suitable combination of any suitable components, devices, or systems carrying out any suitable actions.

FIG. **3** illustrates an example flow diagram **300** for determining problematic paths between interest points in a multi-cloud environment. In certain embodiments, flow diagram **300** is used in cases of no native implementation of cloud triage OAM. Flow diagram **300** may be used by system **100** of FIG. **1**. FIG. **3** includes interest points **310**, a transit router **320**, transit router route tables **330**, and a cloud OAM service device **340**.

In flow diagram **300** of FIG. **3**, a controller (e.g., controller **150** of FIG. **1**) identifies one or more interest points **310** within the network. Interest points **310** are instances within one or more clouds of the network that may host workloads impacted by the problematic event. In the illustrated embodiment of FIG. **3**, interest points **310** are selected based in user intent. Interest points **310** may be located completely in one or more public clouds, in one or more private clouds, or a combination thereof. In the illustrated embodiment of FIG. **3**, the controller identifies interest point **310***a* and interest point **310***b*.

Interest point **310***a* sends traffic **360** to transit router **320**. Transit router **320** is a transit hub used to interconnect one or more cloud networks and/or on-premise data centers. In response to identifying interest points **310**, the controller programs transit router **320** to redirect traffic **360** received from interest point **310***a* to a cloud service agent (e.g., cloud triage agents **170** of FIG. **1**) installed on a cloud service device **340**. In the illustrated embodiment of FIG. **3**, transit router **320** uses transit router route tables **330** to direct traffic **360** to the next destination. Transit router route tables **330** are data tables that include a set of rules for directing incoming network traffic. In certain embodiments, transit router route tables **330** are stored in transit router **320**. As illustrated in FIG. **3**, if transit router **320** determines that incoming traffic **360** is destined for IP address 10.10.10.1/32 associated with interest point **310***b*, transit router **320** redirects traffic **360** to cloud OAM service device **340** in accordance with transit router ingress route table **330***a*.

The service agent installed on cloud OAM service device **340** encapsulates incoming traffic **360** inside a triage data packet (e.g., triage data packet **162** of FIG. **1**) and sends encapsulated data packets **370** to transit router **320** in accordance with transit router egress route table **330***b*. In certain embodiments, encapsulated data packets **370** are in-situ OAM (iOAM) data packets. "In-situ," also known as "in-band," indicates that the operational and telemetry data is carried along with the original data packets rather than being sent within packets specifically dedicated to OAM. In certain embodiments, encapsulated data packets **370** use service packet format **500** described below in FIG. **5**. Transit router **320** sends encapsulated data packets **370** to the next hop. The next hop redirects encapsulated data packets **370** to a cloud OAM service device already inserted in the path and programmed to receive encapsulated data packets **370**. Encapsulated data packets **370** arrives at the destination node associated with interest point **310***b*, where the final characteristics of the path (e.g., OAM telemetry data) is communicated to the controller. As such, cloud OAM service devices work in-line with the actual traffic passing through the cloud OAM service devices.

Once the controller determines to track a network traffic flow, the controller sets up the route for the destination node associated with interest point **310***b* that is being monitored in the different cloud routers (e.g., public or private cloud routers) along the path that have an attached cloud OAM service device. All traffic towards the IP address of the destination node is forwarded to the cloud OAM service device attached to the cloud router. In a public cloud, the cloud router may be in a virtual public cloud (PVC). The first cloud OAM service device creates a copy of each incoming packet. The copy of the incoming packet is an OAM packet that includes an OAM header added by the first cloud OAM service device. The first cloud OAM service device sends the OAM packet in-line with the user traffic flow. The first OAM packet is created when a new flow goes through the cloud OAM service device and is sent ahead of the original packet to the downstream device.

Subsequent OAM packets may be created at a sampled rate. OAM packets sent to the downstream device are forwarded towards other cloud OAM service devices attached to different cloud router hops along the path. The second OAM device sees the OAM packet as the first packet of a new flow and adds its details to the OAM packet instead of creating a new OAM packet. The cloud OAM service device allows the original traffic to flow through and adds its header to the OAM packets which are traversing inline. The final hop cloud OAM service device is determined by performing a lookup of the next hop in the attached router. The next hop may be a Border Gateway Protocol (BGP) session, a transit gateway (TGW) peering, an attached VPC in the cloud, a connected interface on a private cloud router, and the like. The cloud OAM service device in the last hop consumes the OAM packet and generates the OAM results, while allowing the original traffic to flow through as-is.

In certain embodiments, the cloud OAM service device may perform a source lookup in the attached router to determine whether the traffic is coming from an attached network or upstream. The cloud OAM service device may decide whether to generate a new OAM packet or wait to receive an OAM packet from an upstream device to append the incoming OAM packet. In certain embodiments, each cloud OAM service device records the OAM flow data and communicates the OAM flow data to the controller, Accordingly, the controller may identify problematic paths even if one or more OAM packets do not arrive at the final OAM hop.

FIG. **4** illustrates an example OAM packet format **400** that may be used by the systems and diagrams of FIGS. **1** and **2**. OAM packet format **400** includes options to capture cloud native construct details for visibility, path tracing, and the like. In the illustrated embodiment of FIG. **4**, OAM packet format **400** includes a Media Access Control (MAC) header **410**, an EtherType **420**, an IP header **430**, a UDP header **440**, a first cloud OAM option **450**, a second cloud OAM option **460**, an "n" cloud OAM option **470** (where "n" represents any suitable number), and a Cyclic Redundancy Check (CRC) **480**.

MAC header **410** includes the data fields added at the beginning of OAM packet format **400** to turn OAM packet format **400** into a frame that can be transmitted. EtherType **420** is a two-octet field in an Ethernet frame that indicates which protocol (e.g., Internet Protocol version 4 (IPv4), IPv6, etc.) is encapsulated in the payload of the frame. EtherType **420** may be used at the receiving end by the data link layer to determine how the payload of OAM packet format **400** is processed. IP header **430** is a field (e.g., an 8-bit number) that defines which protocol (e.g., Transmission Control Protocol (TCP), User Datagram Protocol (UDP), etc.) is used inside the IP packet. In the illustrated embodiment of FIG. **4**, IP header **430** indicates that the UDP protocol is being used. In certain embodiments, UDP header **440** is 8-byte fixed and simple header. In the illustrated embodiment of FIG. **4**, the UDP header port number LA represents cloud OAM.

First cloud OAM option **450** includes OAM data. First cloud OAM option **450** includes cloud OAM option type **552**, cloud OAM provider ID **554**, and cloud OAM option data **556**. Cloud OAM option type **552** indicates the type of cloud computing service (e.g., private cloud, public cloud, hybrid cloud, multi-cloud, etc.). Cloud OAM provider ID **554** indicates the identity of the cloud provider (e.g., Microsoft Azure, AWS, etc.). Cloud OAM option data **556** captures the cloud construct details for visibility, path tracing, and the like. In certain embodiments, cloud OAM option data **556** captures cloud construct details in private clouds connected to public clouds in hybrid deployment models. Cloud OAM option data **556** may include a Location field, Device ID field, an Attachment ID field, a Route Table ID field, a Timestamp field, and the like.

The Location field encapsulates the cloud region (e.g. cloud regions **120** f FIG. **1**) where the gateway/OAM service agent node resides in the public cloud. This field can also encapsulate the location of the gateways/OAM service nodes in private clouds for hybrid cloud deployments. The Device ID field of cloud OAM option data **556** encapsulates the identity of the public cloud gateway/OAM service agent node. This field may also encapsulate the identity of the gateways/OAM service nodes in private clouds for hybrid cloud deployments. The Attachment ID field of cloud OAM option data **556** encapsulates the interface ID of the private cloud or cloud native routers and paths.

The Route Table ID field of cloud OAM option data **556** encapsulates the route table details of the public cloud native routers or private cloud routers where the OAM path is traversed. The Timestamp field of cloud OAM option data **556** timestamps when the cloud OAM packet reached and left the public cloud native routers/OAM service nodes as well as private cloud routers and other cloud OAM capable devices. Second cloud OAM option **460** and "n" cloud OAM option **470** may collect additional telemetry data such as cloud region identifications, availability zone indications, cloud edge locations, path type identifications, latency, jitter, packet drop, etc. CRC 480 is an error-detecting code. CRC 480 may include a 4 Byte field that includes a 32-bits hash code of data that is generated over the Destination Address, Source Address, Length, and Data field. If the checksum computed by destination is not the same as sent checksum value, data received is corrupted.

FIG. **5** illustrates an example service packet format **500** that may be used by the systems and diagrams of FIGS. **1** and **3**. Service packet format **500** is used for iOAM data packets such that the operational and telemetry data is carried along with the original data packets rather than being sent within packets specifically dedicated to OAM. Accordingly, service packet format **500** is identical to OAM packet format **400** of FIG. **3** with the exception of an original packet **510**.

FIG. **6** illustrates an example method **600** for determining problematic paths between interest points in a multi-cloud environment. Method **600** begins at step **605**. At step **610**, a controller (e.g., controller **150** of FIG. **1**) identifies a problematic event between a first interest point and a second interest point of a network (e.g., network **110** of FIG. **1**). The problematic event may be, for example, an introduction of latency, jitter, and/or packet drop in the current active path between the first and second interest points that is causing the services and/or workloads on the first and second interest points to work at a sub-optimal level. The first interest point may be associated with a first cloud (e.g., cloud **120***a* of FIG. **1**), and the second interest point may be associated with a second cloud (e.g., cloud **120***b* of FIG. **1**). For example, the first interest point may be located within Azure's cloud computing platform, and the second interest point may be located within AWS's cloud computing platform. Method **600** then moves from step **610** to step **615**.

At step **615** of method **600**, the controller activates a first endpoint (e.g., cloud triage endpoint **160***a* of FIG. **1**) associated with the first interest point and a second endpoint (e.g., cloud triage endpoint **160***b* of FIG. **1**) associated with the second interest point. In certain embodiments, the controller activates the first and second endpoints in response to identifying the problematic event between the first and second interest points. The first and/or second endpoints initiate OAM data packets (e.g., triage data packets **162** of FIG. **2**) along the available paths from the first interest point to the second interest point. Method **600** then moves from step **615** to step **620**.

At step **620** of method **600**, the controller receives, from the first and/or second endpoints, telemetry data (e.g., cloud triage telemetry data **190** of FIG. **1**) collected by the OAM data packets. The telemetry data collected by the OAM packets includes information such as cloud region identifications, availability zone indications, cloud edge locations, path type identifications, latency, jitter, packet drop, etc. Method **600** then moves from step **620** to step **625**, where the controller determines the problematic path between the first interest point and the second interest point using the telemetry data received from activated first and/or second endpoints. The problematic path is the path causing the problematic event. The controller may build the problematic path by determining each node along the path. Method **600** then moves from step **625** to step **630**.

At step **630** of method **600**, the controller determines whether one or more available unproblematic paths exist between the first interest point and the second interest point. For example, the controller may use the telemetry data received from the first and/or second endpoints to determine one or more available alternative paths between the first and second interest points. If the controller determines that an available unproblematic path exists between the first interest point and the second interest point, method **600** moves from step **630** to step **635**, where the controller instructs the first endpoint and/or the second endpoint to direct traffic along the available unproblematic path. Method **600** then moves from step **635** to step **640**, where method **600** ends. If, at step

630, the controller determines that an available unproblematic path does not exist between the first interest point and the second interest point, method 600 advances from step 630 to step 640, where method 600 ends.

Although this disclosure describes and illustrates particular steps of the method of FIG. 6 as occurring in a particular order, this disclosure contemplates any suitable steps of the method of FIG. 6 occurring in any suitable order. Although this disclosure describes and illustrates an example method for determining problematic paths between interest points in a multi-cloud environment including the particular steps of the method of FIG. 6, this disclosure contemplates any suitable method for determining problematic paths between interest points in a multi-cloud environment including any suitable steps, which may include all, some, or none of the steps of the method of FIG. 6, where appropriate. For example, method 600 may include a step where the controller integrates triage agents at one or more locations (e.g., within a private cloud, a public cloud, an on-premise data center, etc.) within the network. As another example, method 600 may include a step where the controller instructs a transit router to redirect an identified traffic flow to a cloud service agent.

Although this disclosure describes and illustrates particular components, devices, or systems carrying out particular steps of the method of FIG. 6, this disclosure contemplates any suitable combination of any suitable components, devices, or systems carrying out any suitable steps of the method of FIG. 6. For example, one or more nodes of the network (e.g., a cloud triage endpoint, a cloud OAM service device, etc.) may perform one or more steps of method 600.

FIG. 7 illustrates an example computer system 700. In particular embodiments, one or more computer systems 700 perform one or more steps of one or more methods described or illustrated herein. In particular embodiments, one or more computer systems 700 provide functionality described or illustrated herein. In particular embodiments, software running on one or more computer systems 700 performs one or more steps of one or more methods described or illustrated herein or provides functionality described or illustrated herein. Particular embodiments include one or more portions of one or more computer systems 700. Herein, reference to a computer system may encompass a computing device, and vice versa, where appropriate. Moreover, reference to a computer system may encompass one or more computer systems, where appropriate.

This disclosure contemplates any suitable number of computer systems 700. This disclosure contemplates computer system 700 taking any suitable physical form. As example and not by way of limitation, computer system 700 may be an embedded computer system, a system-on-chip (SOC), a single-board computer system (SBC) (such as, for example, a computer-on-module (COM) or system-on-module (SOM)), a desktop computer system, a laptop or notebook computer system, an interactive kiosk, a mainframe, a mesh of computer systems, a mobile telephone, a personal digital assistant (PDA), a server, a tablet computer system, an augmented/virtual reality device, or a combination of two or more of these. Where appropriate, computer system 700 may include one or more computer systems 700; be unitary or distributed; span multiple locations; span multiple machines; span multiple data centers; or reside in a cloud, which may include one or more cloud components in one or more networks. Where appropriate, one or more computer systems 700 may perform without substantial spatial or temporal limitation one or more steps of one or more methods described or illustrated herein. As an example and not by way of limitation, one or more computer systems 700 may perform in real time or in batch mode one or more steps of one or more methods described or illustrated herein. One or more computer systems 700 may perform at different times or at different locations one or more steps of one or more methods described or illustrated herein, where appropriate.

In particular embodiments, computer system 700 includes a processor 702, memory 704, storage 706, an input/output (I/O) interface 708, a communication interface 710, and a bus 712. Although this disclosure describes and illustrates a particular computer system having a particular number of particular components in a particular arrangement, this disclosure contemplates any suitable computer system having any suitable number of any suitable components in any suitable arrangement.

In particular embodiments, processor 702 includes hardware for executing instructions, such as those making up a computer program. As an example and not by way of limitation, to execute instructions, processor 702 may retrieve (or fetch) the instructions from an internal register, an internal cache, memory 704, or storage 706; decode and execute them; and then write one or more results to an internal register, an internal cache, memory 704, or storage 706. In particular embodiments, processor 702 may include one or more internal caches for data, instructions, or addresses. This disclosure contemplates processor 702 including any suitable number of any suitable internal caches, where appropriate. As an example and not by way of limitation, processor 702 may include one or more instruction caches, one or more data caches, and one or more translation lookaside buffers (TLBs). Instructions in the instruction caches may be copies of instructions in memory 704 or storage 706, and the instruction caches may speed up retrieval of those instructions by processor 702. Data in the data caches may be copies of data in memory 704 or storage 706 for instructions executing at processor 702 to operate on; the results of previous instructions executed at processor 702 for access by subsequent instructions executing at processor 702 or for writing to memory 704 or storage 706; or other suitable data. The data caches may speed up read or write operations by processor 702. The TLBs may speed up virtual-address translation for processor 702. In particular embodiments, processor 702 may include one or more internal registers for data, instructions, or addresses. This disclosure contemplates processor 702 including any suitable number of any suitable internal registers, where appropriate. Where appropriate, processor 702 may include one or more arithmetic logic units (ALUs); be a multi-core processor; or include one or more processors 702. Although this disclosure describes and illustrates a particular processor, this disclosure contemplates any suitable processor.

In particular embodiments, memory 704 includes main memory for storing instructions for processor 702 to execute or data for processor 702 to operate on. As an example and not by way of limitation, computer system 700 may load instructions from storage 706 or another source (such as, for example, another computer system 700) to memory 704. Processor 702 may then load the instructions from memory 704 to an internal register or internal cache. To execute the instructions, processor 702 may retrieve the instructions from the internal register or internal cache and decode them. During or after execution of the instructions, processor 702 may write one or more results (which may be intermediate or final results) to the internal register or internal cache. Processor 702 may then write one or more of those results to memory 704. In particular embodiments, processor 702 executes only instructions in one or more internal registers or internal caches or in memory **704** (as opposed to storage **706** or elsewhere) and operates only on data in one or more internal registers or internal caches or in memory **704** (as opposed to storage **706** or elsewhere). One or more memory buses (which may each include an address bus and a data bus) may couple processor **702** to memory **704**. Bus **712** may include one or more memory buses, as described below. In particular embodiments, one or more memory management units (MMUs) reside between processor **702** and memory **704** and facilitate accesses to memory **704** requested by processor **702**. In particular embodiments, memory **704** includes random access memory (RAM). This RAM may be volatile memory, where appropriate. Where appropriate, this RAM may be dynamic RAM (DRAM) or static RAM (SRAM). Moreover, where appropriate, this RAM may be single-ported or multi-ported RAM. This disclosure contemplates any suitable RAM. Memory **704** may include one or more memories **704**, where appropriate. Although this disclosure describes and illustrates particular memory, this disclosure contemplates any suitable memory.

In particular embodiments, storage **706** includes mass storage for data or instructions. As an example and not by way of limitation, storage **706** may include a hard disk drive (HDD), a floppy disk drive, flash memory, an optical disc, a magneto-optical disc, magnetic tape, or a Universal Serial Bus (USB) drive or a combination of two or more of these. Storage **706** may include removable or non-removable (or fixed) media, where appropriate. Storage **706** may be internal or external to computer system **700**, where appropriate. In particular embodiments, storage **706** is non-volatile, solid-state memory. In particular embodiments, storage **706** includes read-only memory (ROM). Where appropriate, this ROM may be mask-programmed ROM, programmable ROM (PROM), erasable PROM (EPROM), electrically erasable PROM (EEPROM), electrically alterable ROM (EAROM), or flash memory or a combination of two or more of these. This disclosure contemplates mass storage **706** taking any suitable physical form. Storage **706** may include one or more storage control units facilitating communication between processor **702** and storage **706**, where appropriate. Where appropriate, storage **706** may include one or more storages **706**. Although this disclosure describes and illustrates particular storage, this disclosure contemplates any suitable storage.

In particular embodiments, I/O interface **708** includes hardware, software, or both, providing one or more interfaces for communication between computer system **700** and one or more I/O devices. Computer system **700** may include one or more of these I/O devices, where appropriate. One or more of these I/O devices may enable communication between a person and computer system **700**. As an example and not by way of limitation, an I/O device may include a keyboard, keypad, microphone, monitor, mouse, printer, scanner, speaker, still camera, stylus, tablet, touch screen, trackball, video camera, another suitable I/O device or a combination of two or more of these. An I/O device may include one or more sensors. This disclosure contemplates any suitable I/O devices and any suitable I/O interfaces **708** for them. Where appropriate, I/O interface **708** may include one or more device or software drivers enabling processor **702** to drive one or more of these I/O devices. I/O interface **708** may include one or more I/O interfaces **708**, where appropriate. Although this disclosure describes and illustrates a particular I/O interface, this disclosure contemplates any suitable I/O interface.

In particular embodiments, communication interface **710** includes hardware, software, or both providing one or more interfaces for communication (such as, for example, packet-based communication) between computer system **700** and one or more other computer systems **700** or one or more networks. As an example and not by way of limitation, communication interface **710** may include a network interface controller (NIC) or network adapter for communicating with an Ethernet or other wire-based network or a wireless NIC (WNIC) or wireless adapter for communicating with a wireless network, such as a WI-FI network. This disclosure contemplates any suitable network and any suitable communication interface **710** for it. As an example and not by way of limitation, computer system **700** may communicate with an ad hoc network, a personal area network (PAN), a LAN, a WAN, a MAN, or one or more portions of the Internet or a combination of two or more of these. One or more portions of one or more of these networks may be wired or wireless. As an example, computer system **700** may communicate with a wireless PAN (WPAN) (such as, for example, a BLUETOOTH WPAN), a WI-FI network, a WI-MAX network, a cellular telephone network (such as, for example, a Global System for Mobile Communications (GSM) network, a 3G network, a 4G network, a 5G network, an LTE network, or other suitable wireless network or a combination of two or more of these. Computer system **700** may include any suitable communication interface **710** for any of these networks, where appropriate. Communication interface **710** may include one or more communication interfaces **410**, where appropriate. Although this disclosure describes and illustrates a particular communication interface, this disclosure contemplates any suitable communication interface.

In particular embodiments, bus **712** includes hardware, software, or both coupling components of computer system **700** to each other. As an example and not by way of limitation, bus **712** may include an Accelerated Graphics Port (AGP) or other graphics bus, an Enhanced Industry Standard Architecture (EISA) bus, a front-side bus (FSB), a HYPERTRANSPORT (HT) interconnect, an Industry Standard Architecture (ISA) bus, an INFINIBAND interconnect, a low-pin-count (LPC) bus, a memory bus, a Micro Channel Architecture (MCA) bus, a Peripheral Component Interconnect (PCI) bus, a PCI-Express (PCIe) bus, a serial advanced technology attachment (SATA) bus, a Video Electronics Standards Association local (VLB) bus, or another suitable bus or a combination of two or more of these. Bus **712** may include one or more buses **712**, where appropriate. Although this disclosure describes and illustrates a particular bus, this disclosure contemplates any suitable bus or interconnect.

Herein, a computer-readable non-transitory storage medium or media may include one or more semiconductor-based or other integrated circuits (ICs) (such, as for example, field-programmable gate arrays (FPGAs) or application-specific ICs (ASICs)), hard disk drives (HDDs), hybrid hard drives (HHDs), optical discs, optical disc drives (ODDs), magneto-optical discs, magneto-optical drives, floppy diskettes, floppy disk drives (FDDs), magnetic tapes, solid-state drives (SSDs), RAM-drives, SECURE DIGITAL cards or drives, any other suitable computer-readable non-transitory storage media, or any suitable combination of two or more of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.

Herein, "or" is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A or B” means “A, B, or both,” unless expressly indicated otherwise or indicated otherwise by context. Moreover, “and” is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A and B” means “A and B, jointly or severally,” unless expressly indicated otherwise or indicated otherwise by context.

The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, feature, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Furthermore, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative. Additionally, although this disclosure describes or illustrates particular embodiments as providing particular advantages, particular embodiments may provide none, some, or all of these advantages.

What is claimed is:

1. A network component, comprising:

one or more processors; and

one or more computer-readable non-transitory storage media coupled to the one or more processors and comprising instructions that, when executed by the one or more processors, cause the network component to perform operations comprising:

identifying a problematic event between a first interest point and a second interest point of a network;

activating a first endpoint associated with the first interest point and a second endpoint associated with the second interest point, wherein:

activating the first endpoint and the second endpoint initiates a generation of Operations, Administration, and Maintenance (OAM) out-of- band data packets by the first endpoint and the second endpoint; and

each of the OAM out-of-band data packets uses an OAM packet format, the OAM packet format comprising:

a Media Access Control (MAC) header;

an EtherType;

an Internet Protocol (IP) header;

a User Datagram Protocol (UDP) header;

at least one cloud OAM option; and

a Cyclic Redundancy Check (CRC);

receiving, from the first endpoint and the second endpoint, telemetry data associated with a problematic path between the first interest point and the second interest point; and

determining the problematic path between the first interest point and the second interest point using the telemetry data received from the first endpoint and the second endpoint, wherein the telemetry data is collected by the OAM out-of-band data packets.

2. The network component of claim **1**, wherein the telemetry data comprises an identity of one or more cloud providers.

3. The network component of claim **1**, wherein each of the first interest point and the second interest point are associated with one of the following:

a public cloud;

a private cloud; or

an on-premise data center.

4. The network component of claim **1**, wherein the problematic event is associated with at least one of the following network characteristics:

latency;

jitter; or

packet drop.

5. The network component of claim **1**, wherein the at least one cloud OAM option comprises a cloud OAM option type, a cloud OAM provider ID, and cloud OAM option data.

6. The network component of claim **1**, the operations further comprising:

activating one or more cloud agents within the network;

receiving, from the one or more cloud agents, additional telemetry data associated with the problematic path between the first interest point and the second interest point; and

computing the problematic path between the first interest point and the second interest point using the additional telemetry data received from the one or more cloud agents.

7. The network component of claim **1**, the operations further comprising instructing one or more transit routers within the network to redirect an identified traffic flow to a cloud agent.

8. A method, comprising:

identifying a problematic event between a first interest point and a second interest point of a network;

activating a first endpoint associated with the first interest point and a second endpoint associated with the second interest point, wherein:

activating the first endpoint and the second endpoint initiates a generation of Operations, Administration, and Maintenance (OAM) out-of-band data packets by the first endpoint and the second endpoint; and

each of the OAM out-of-band data packets uses an OAM packet format, the OAM packet format comprising:

a Media Access Control (MAC) header;

an EtherType;

an Internet Protocol (IP) header;

a User Datagram Protocol (UDP) header;

at least one cloud OAM option; and

a Cyclic Redundancy Check (CRC);

receiving, from the first endpoint and the second endpoint, telemetry data associated with a problematic path between the first interest point and the second interest point; and

determining the problematic path between the first interest point and the second interest point using the telemetry data received from the first endpoint and the second endpoint, wherein the telemetry data is collected by the OAM out-of-band data packets.

9. The method of claim **8**, wherein the telemetry data comprises an identity of one or more cloud providers.

10. The method of claim 8, wherein each of the first interest point and the second interest point are associated with one of the following:

a public cloud;

a private cloud; or

an on-premise data center.

11. The method of claim 8, wherein the problematic event is associated with at least one of the following network characteristics:

latency;

jitter; or

packet drop.

12. The method of claim 8, wherein the at least one cloud OAM option comprises a cloud OAM option type, a cloud OAM provider ID, and cloud OAM option data.

13. The method of claim 8, further comprising:

activating one or more cloud agents within the network;

receiving, from the one or more cloud agents, additional telemetry data associated with the problematic path between the first interest point and the second interest point; and

computing the problematic path between the first interest point and the second interest point using the additional telemetry data received from the one or more cloud agents.

14. The method of claim 8, further comprising instructing one or more transit routers within the network to redirect an identified traffic flow to a cloud agent.

15. One or more computer-readable non-transitory storage media embodying instructions that, when executed by a processor, cause the processor to perform operations comprising:

identifying a problematic event between a first interest point and a second interest point of a network;

activating a first endpoint associated with the first interest point and a second endpoint associated with the second interest point, wherein:

activating the first endpoint and the second endpoint initiates a generation of Operations, Administration, and Maintenance (OAM) out-of-band data packets by the first endpoint and the second endpoint; and

each of the OAM out-of-band data packets uses an OAM packet format, the OAM packet format comprising:

a Media Access Control (MAC) header;

an EtherType;

an Internet Protocol (IP) header;

a User Datagram Protocol (UDP) header;

at least one cloud OAM option; and

a Cyclic Redundancy Check (CRC);

receiving, from the first endpoint and the second endpoint, telemetry data associated with a problematic path between the first interest point and the second interest point; and

determining the problematic path between the first interest point and the second interest point using the telemetry data received from the first endpoint and the second endpoint, wherein the telemetry data is collected by the OAM out-of-band data packets.

16. The or more computer-readable non-transitory storage media of claim 15, wherein the telemetry data comprises an identity of one or more cloud providers.

17. The or more computer-readable non-transitory storage media of claim 15, wherein each of the first interest point and the second interest point are associated with one of the following:

a public cloud;

a private cloud; or

an on-premise data center.

18. The or more computer-readable non-transitory storage media of claim 15, wherein the problematic event is associated with at least one of the following network characteristics:

latency;

jitter; or

packet drop.

19. The or more computer-readable non-transitory storage media of claim 15, wherein the at least one cloud OAM option comprises a cloud OAM option type, a cloud OAM provider ID, and cloud OAM option data.

20. The or more computer-readable non-transitory storage media of claim 15, the operations further comprising:

activating one or more cloud agents within the network;

receiving, from the one or more cloud agents, additional telemetry data associated with the problematic path between the first interest point and the second interest point; and

computing the problematic path between the first interest point and the second interest point using the additional telemetry data received from the one or more cloud agents.

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